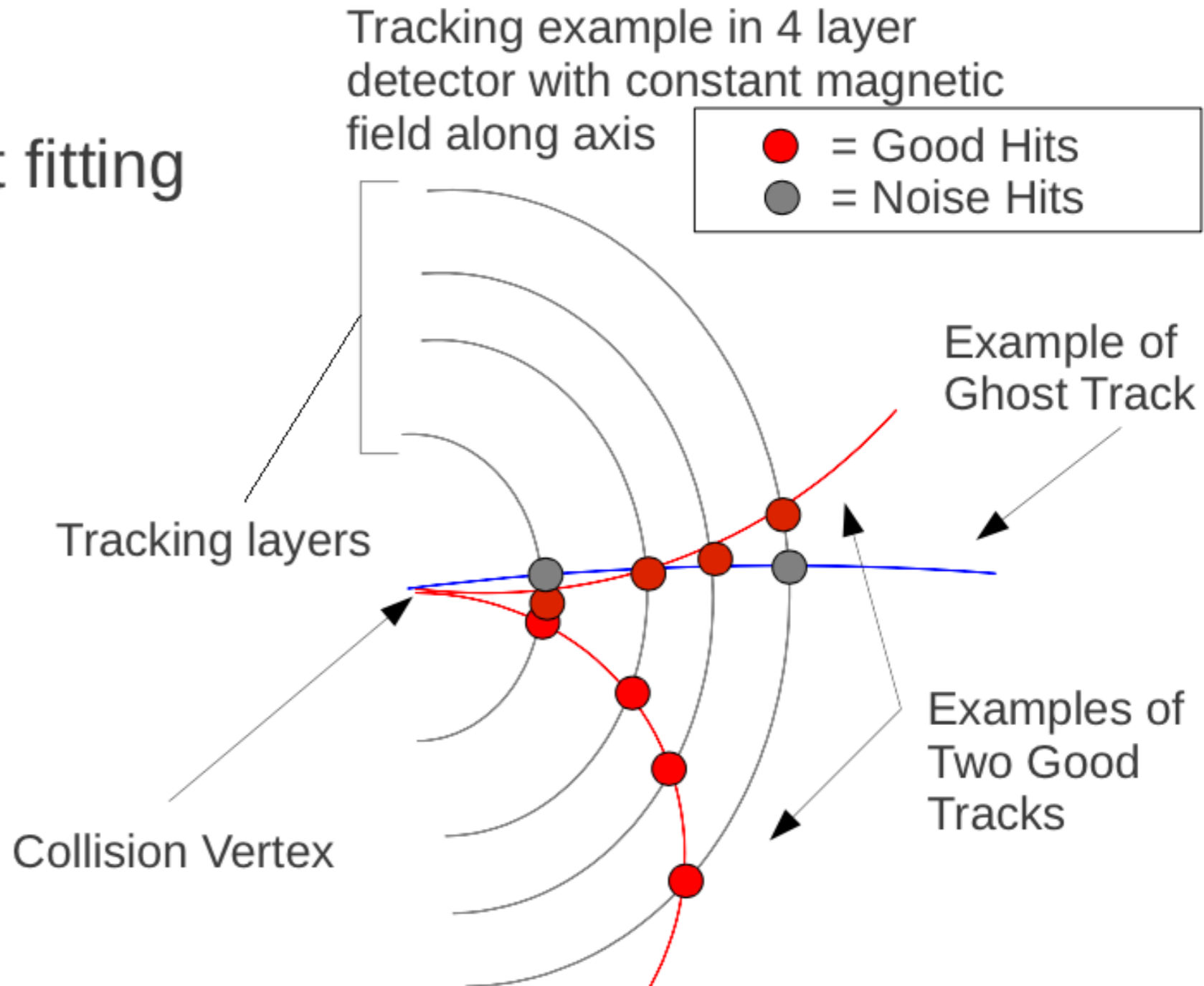# Background

- <u>Basic goal of tracking: to associate clusters together to reconstruct true particle track</u>

- <u>Not</u> necessarily about fitting

- Subgoals:
    - High efficiency
    - Good ghost rejection
    - CPU time/memory

Tracking example in 4 layer detector with constant magnetic field along axis

- ● = Good Hits
- ● = Noise Hits

Example of Ghost Track

Tracking layers

Examples of Two Good Tracks

Collision Vertex

The need for pattern recognition

- **How should we approach tracking?**

- One possibility: brute force method

  - Makes track candidates of
    all possible combinations of the hits

  - Perform some ghost rejection:

    - Would require fitting ALL tracks and
      keeping combinations of hits which pass a χ^2 cut

  - The highest efficiency possible

  - Will have a gigantic amount of ghosts

  - Algorithmic time scales with (n)^layers

● Hits in detector

n hits in detector
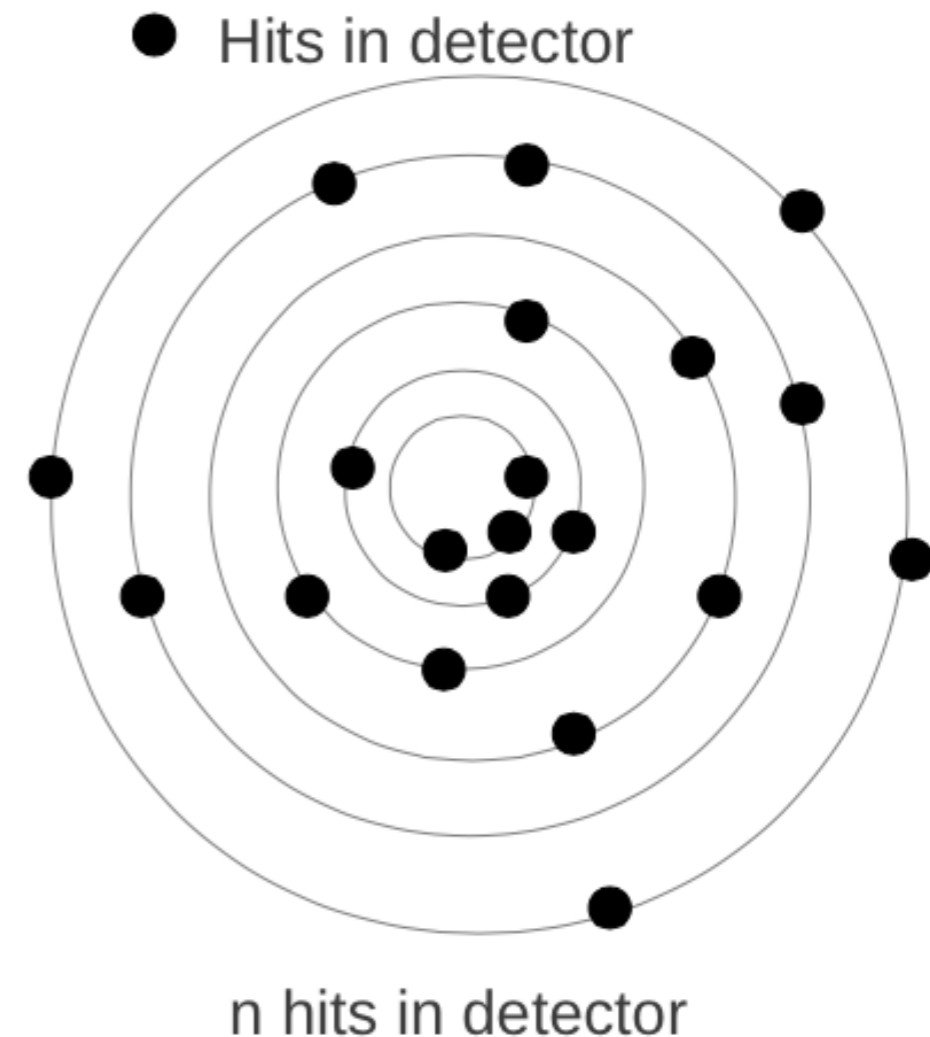
We can do a lot better than this just by inventing smarter ways
to make track candidates
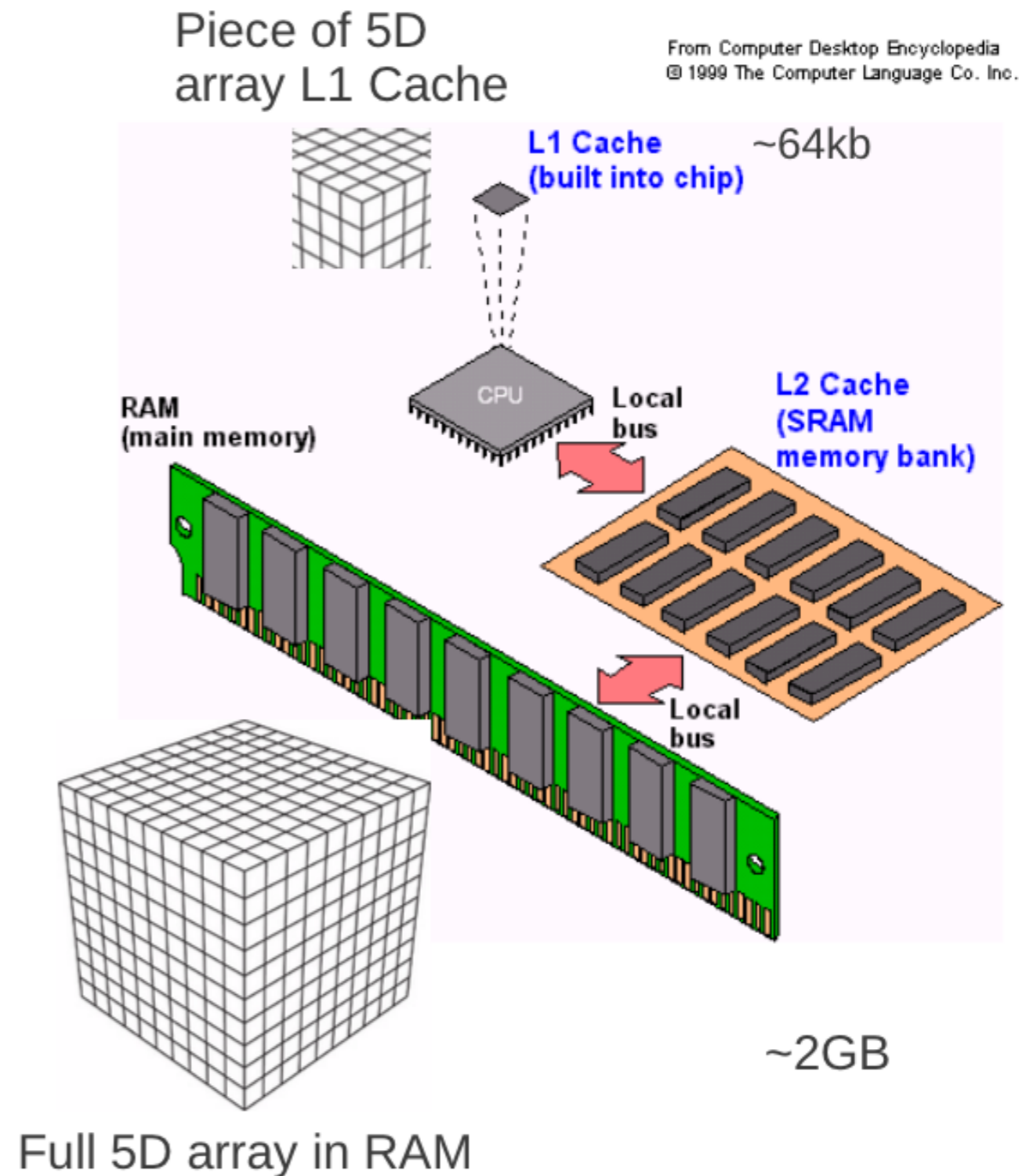
Hough Pattern Recognition

- **How should we approach tracking?**

- One possibility: brute force method

  - Makes track candidates of
    all possible combinations of the hits

  - Perform some ghost rejection:

    - Would require fitting ALL tracks and
      keeping combinations of hits which pass a χ^2 cut

  - The highest efficiency possible

  - Will have a gigantic amount of ghosts

  - Algorithmic time scales with $(n)^{layers}$

● Hits in detector

n hits in detector
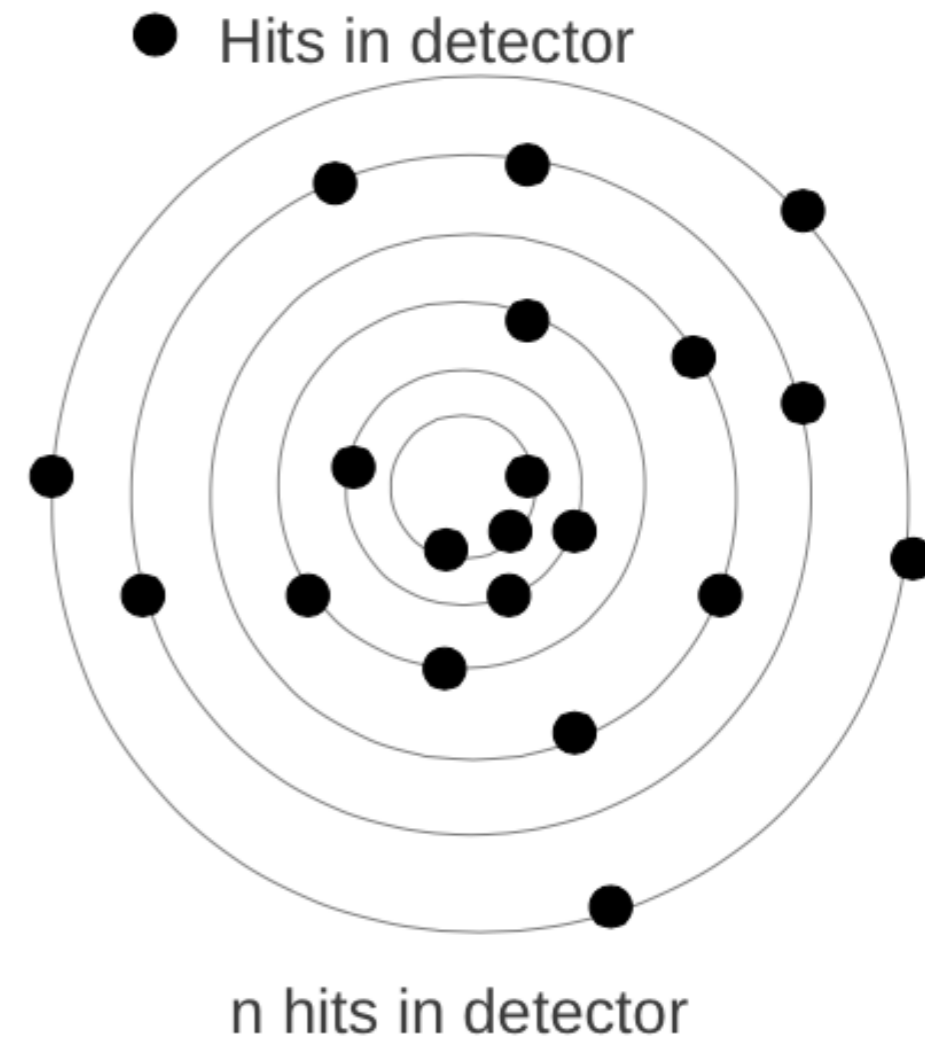
We can do a lot better than this just by inventing smarter ways to make track candidates

Limitations at 5D

- If we try to store the 5D hough space with a decent binning in memory, it can't fit into the L1 cache.

- This is a problem because while hough transforming, the 5D hough space is accessed randomly and not contiguously

- Thus the CPU has to constantly clear its cache and grab a new part of the 5D array from RAM: a slow process

Piece of 5D array L1 Cache

From Computer Desktop Encyclopedia
© 1999 The Computer Language Co. Inc.

L1 Cache ~64kb
(built into chip)

RAM
(main memory)

CPU

Local bus

L2 Cache
(SRAM memory bank)

Local bus

~2GB

Full 5D array in RAM

Recursive Solution to Resource Limitations

- Solution: Only create Hough Spaces with binning that can fit into the L1 cache

- In order to get required level of k ~ n^1/2 binning, we "zoom" into the Hough Space

- Take every bin with a lot of overlap, and transform only those points into a new Hough Space with boundaries of the initial bin

- In effect we are creating the fully binned 5D Hough space, one section at a time.

Coarsely binned 5D Hough Space
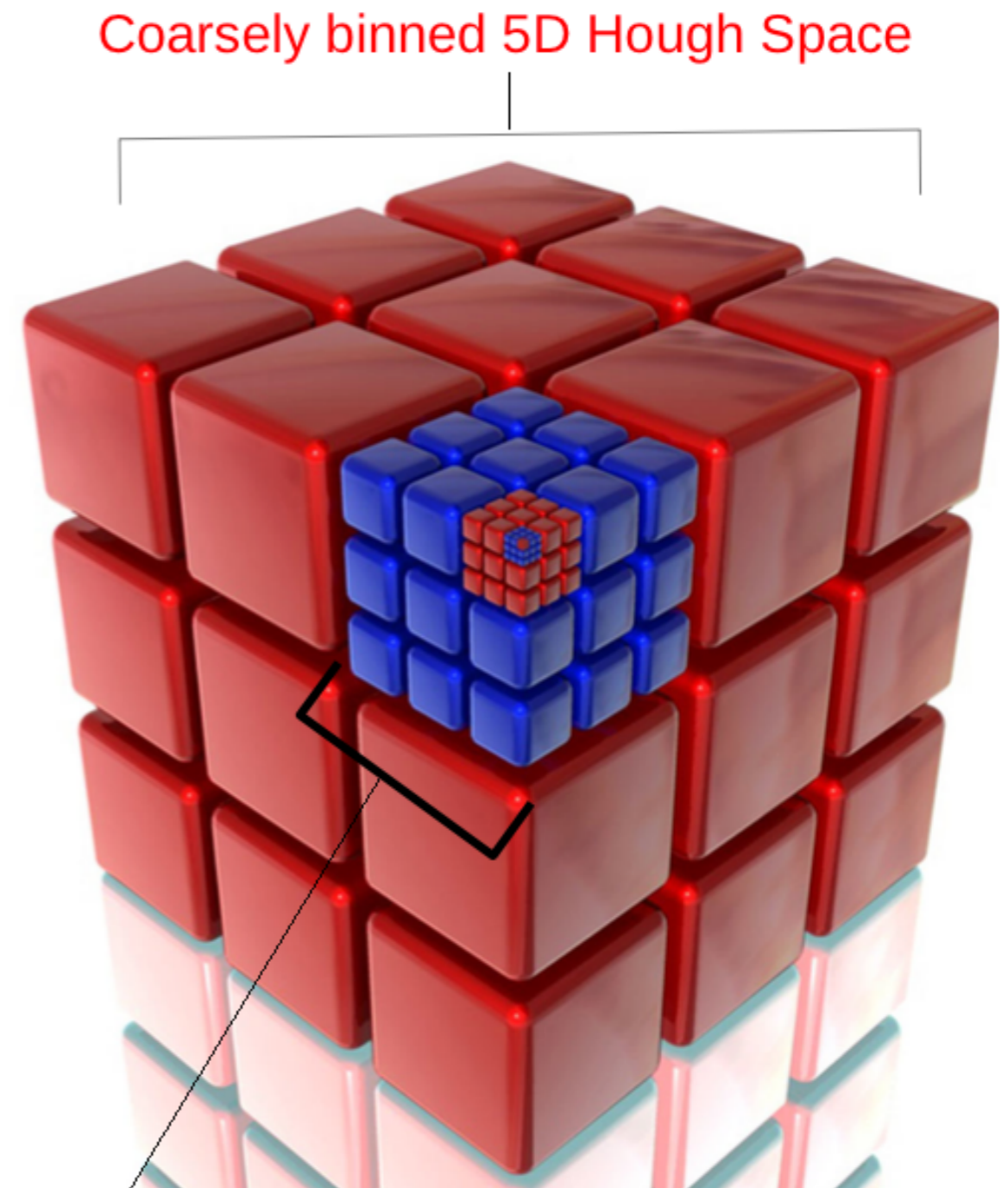
Zoomed In Hough Space

Now that we have zoomed into this piece of hough space, overlap peaks become more meaningful

Hough Transform Performance at Large N

- To perform a Hough Transform on a single point, it takes k^3 iterations because there are only 3 independent parameters

- For n points, it takes n k^3 iterations
  since we know k ~ n^1/2
  the algorithmic time scaling is n^(5/2)

- Recursive zooming adds a factor of log(n)

Algorithmic Time Scaling of Tracking Algorithms

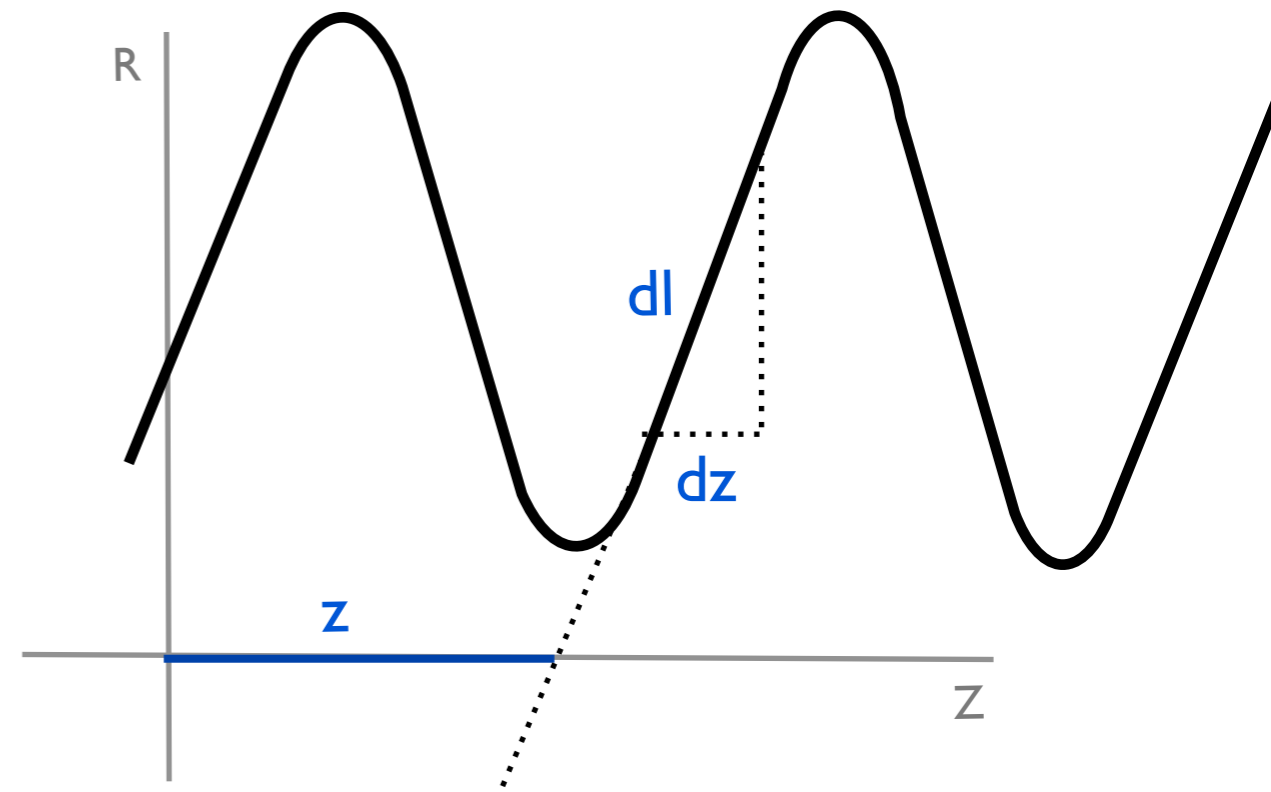| n ~ hits L = layers	Brute Force	Layer Projections	HelixHough
No vertex info	n^L	n^3	$n^{5/2} \log(n)$
With Vertex info	n^{L-1}	n^2	$n^{3/2} \log(n)$

Hough Transform in 5-dimensions

beam eye's view
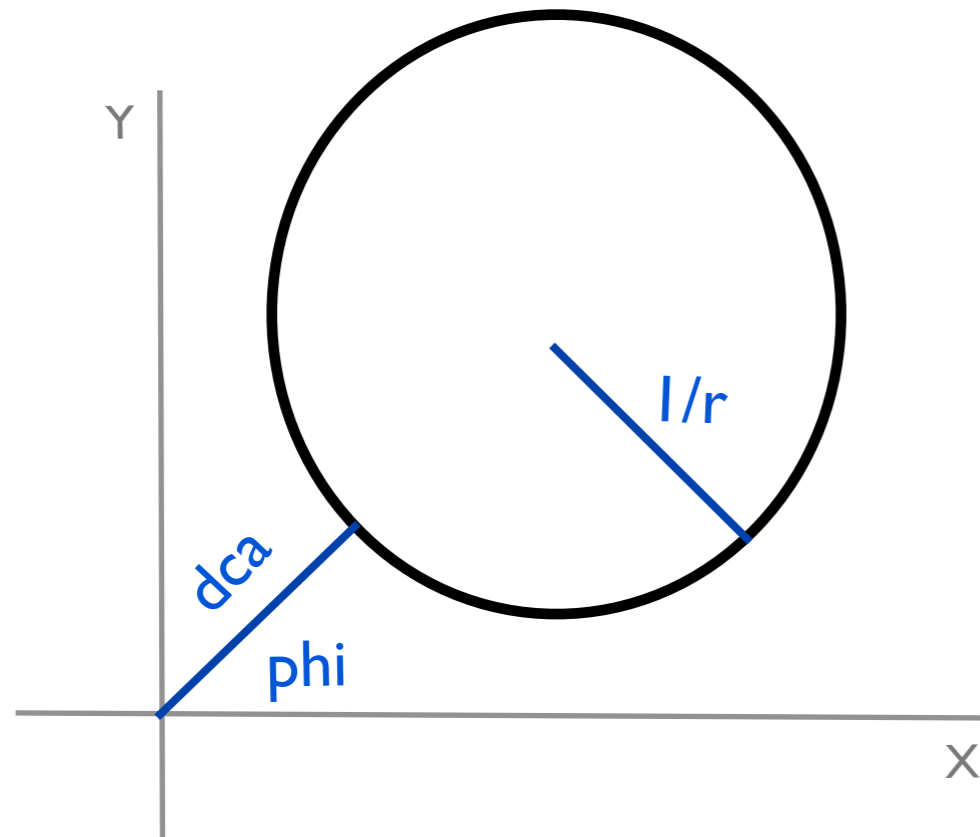
side view

phi: angle to center of rotation

dca: distance of closest approach to origin

kappa = 1/r: curvature in the bend plane

TASK #1: We will change the limits on the "pseudo-rapdity" (dz/dl) and bending (1/r) voting array

z: offset to origin

dz/dl: run in z over length along curve

TASK #2: We will need a real field kalman fitter to be developed, since our field is less constant

sPHENIX MIE reference design tracking

EMCAL

R= 80.0cm ɸ strip)

η=0.0

η=+1.1

R= 45.5cm (U strip)

R= 44..5cm (ɸ strip)

R= 10.5cm (U strip)

R= 9.5cm (ɸ strip)

R= 4.6cm (VTX Pixel)

R= 2.7cm (VTX Pixel)

Extended radial reach for **improved resolution**

Shared support for outer tracking momentum and pattern recognition layers for **material budgeting**
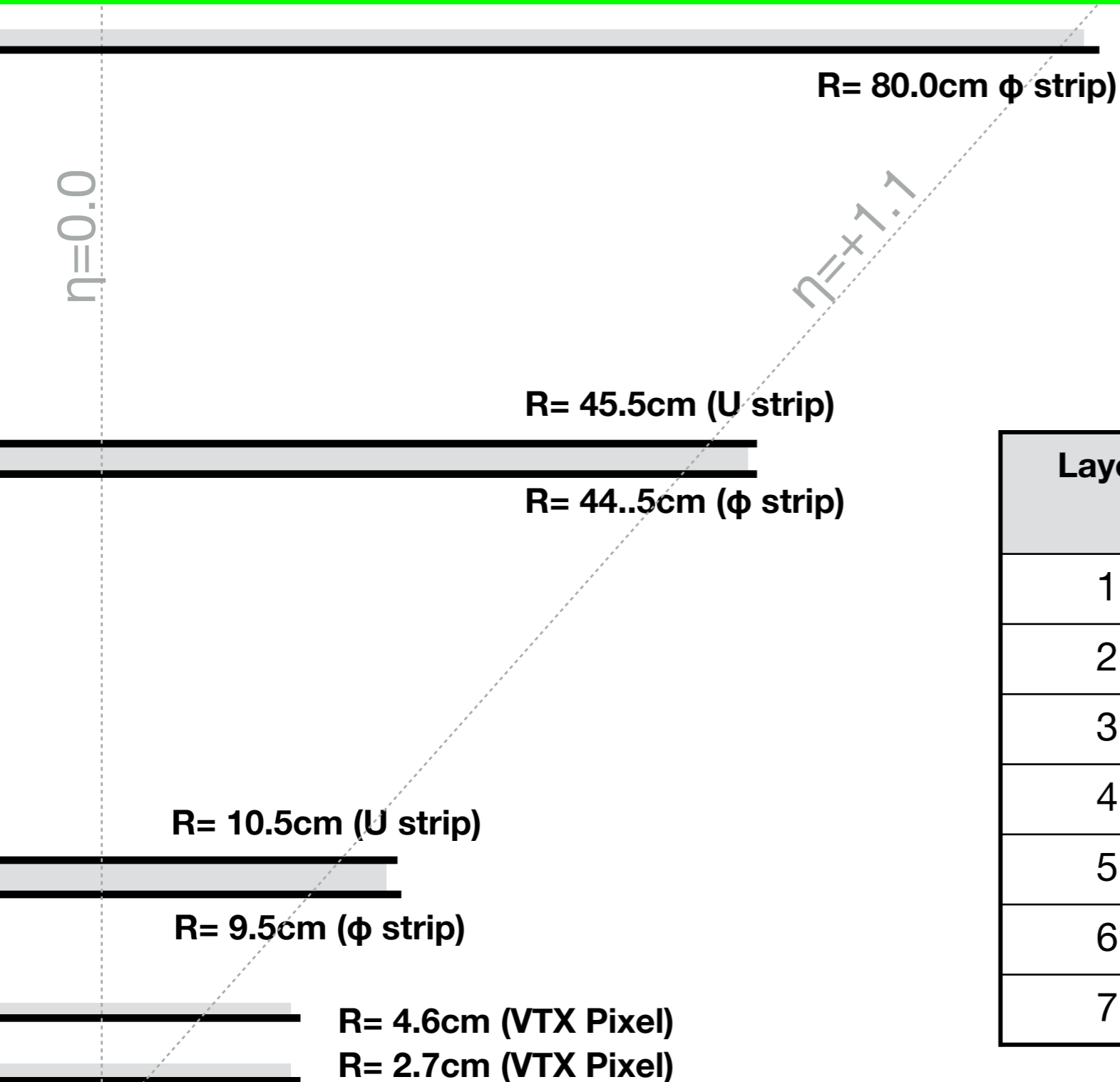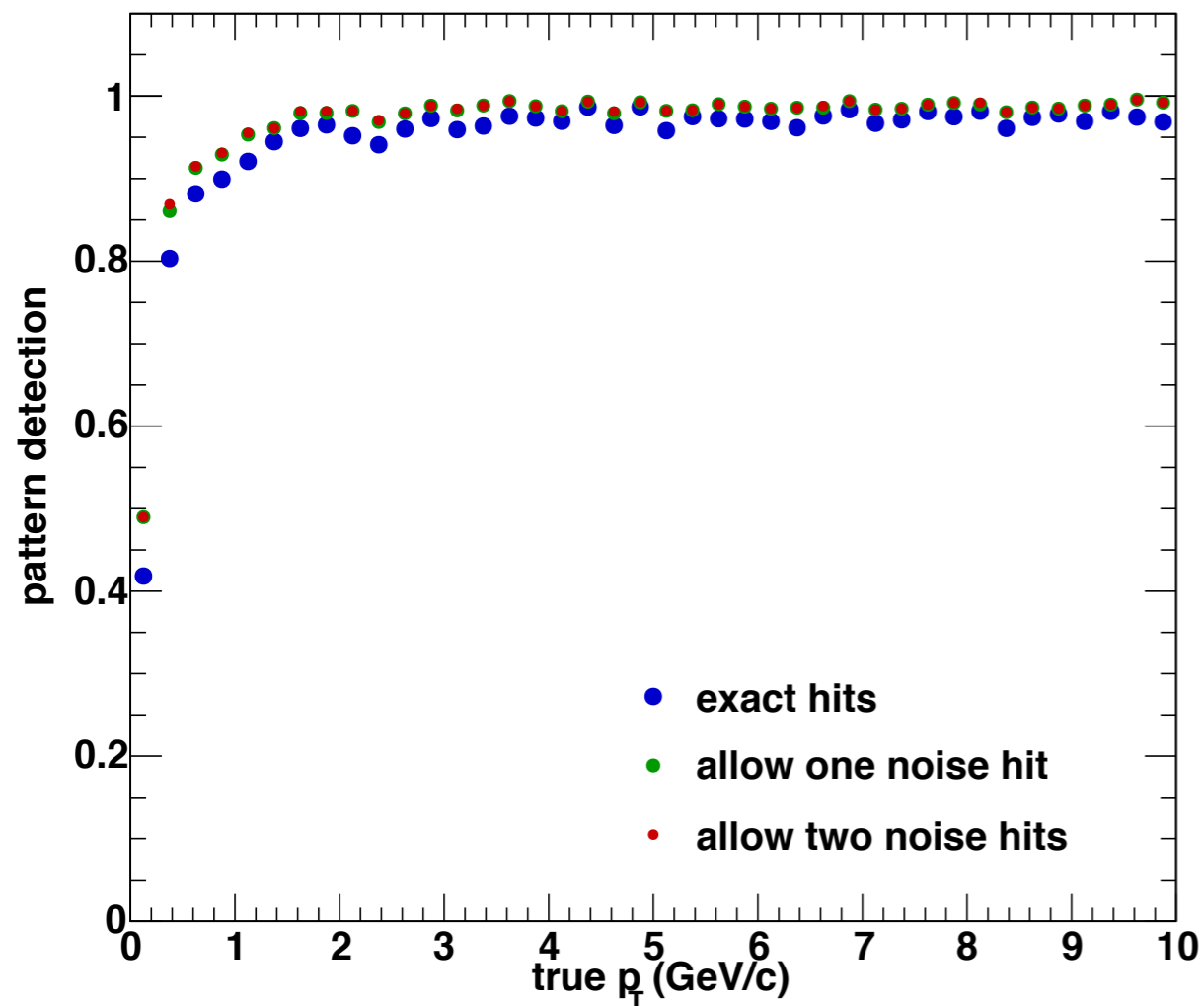
| Layer	ɸ pitch (um)	z pitch (mm)	Thickness (%)
1	50	0.425	1.3
2	50	0.425	1.3
3	60	8	2.7
4	*240*	*2*	
5	60	8	2.0
6	*240*	*2*	
7	60	8	2.0

sPHENIX Performance Measures

…in central 0-5% Au+Au…

pattern detection efficiency
"How often are we finding the hits
left by a real particle?"

tracking purity
"In our output, how often are all the hits from
the same particle?"

- exact hits
- allow one noise hit
- allow two noise hits

- 7 hits
- ≥6 hits
- ≥5 hits
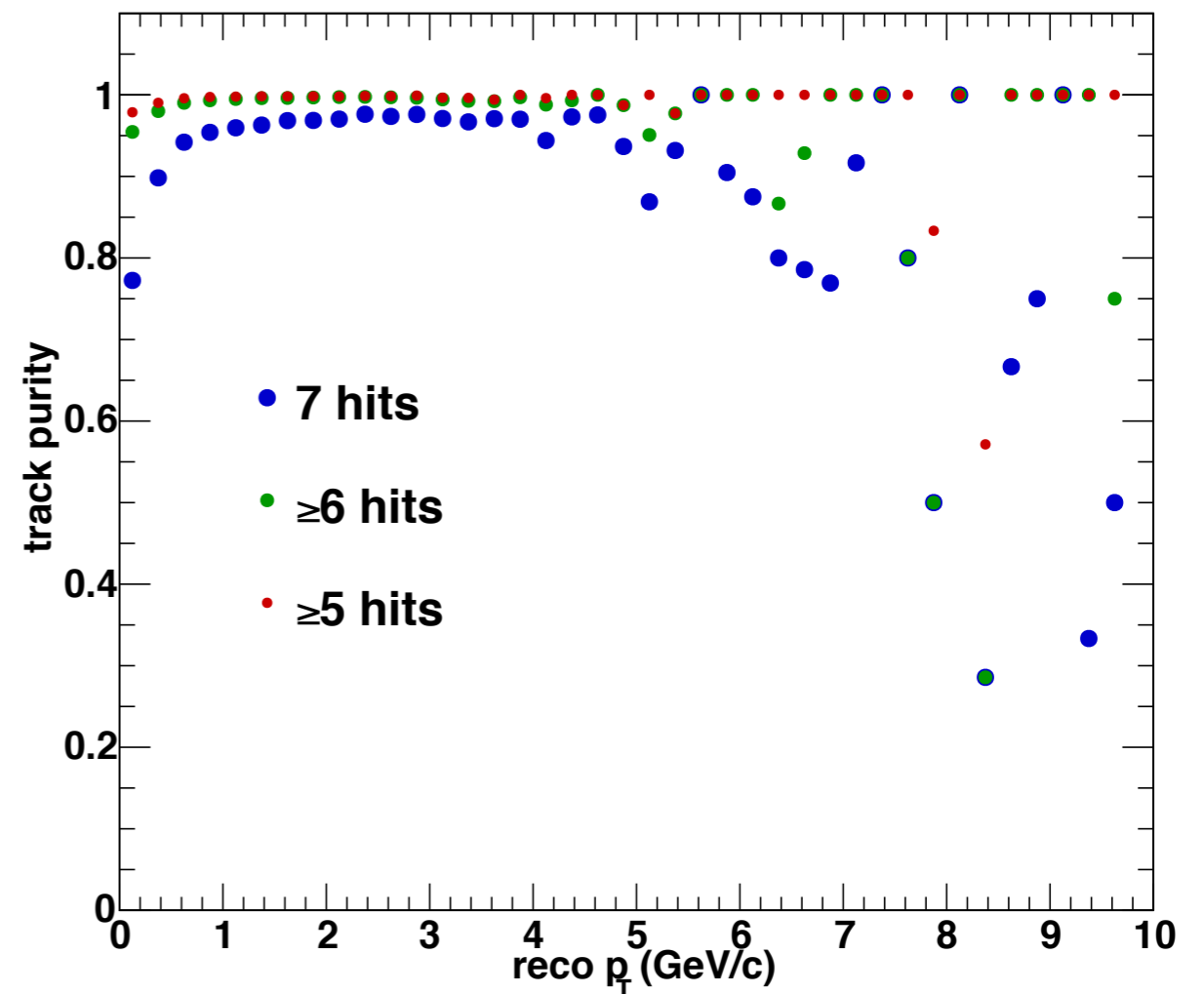
>95% in most cases, lowest momenta become more challenging due to
bend producing a large phase space for backgrounds

sPHENIX Performance Measures

…after a scale correction of 1.6%, we have give momentum resolution…

$\Delta p_T / p_T = 1.31\text{E-}02 + p_T \times 2.53\text{E-}04$

$Y(1S,2S,3S) \rightarrow e^+e^-$

p+p, 10 weeks

$\sigma_{1S} = 99 \pm 2$ MeV